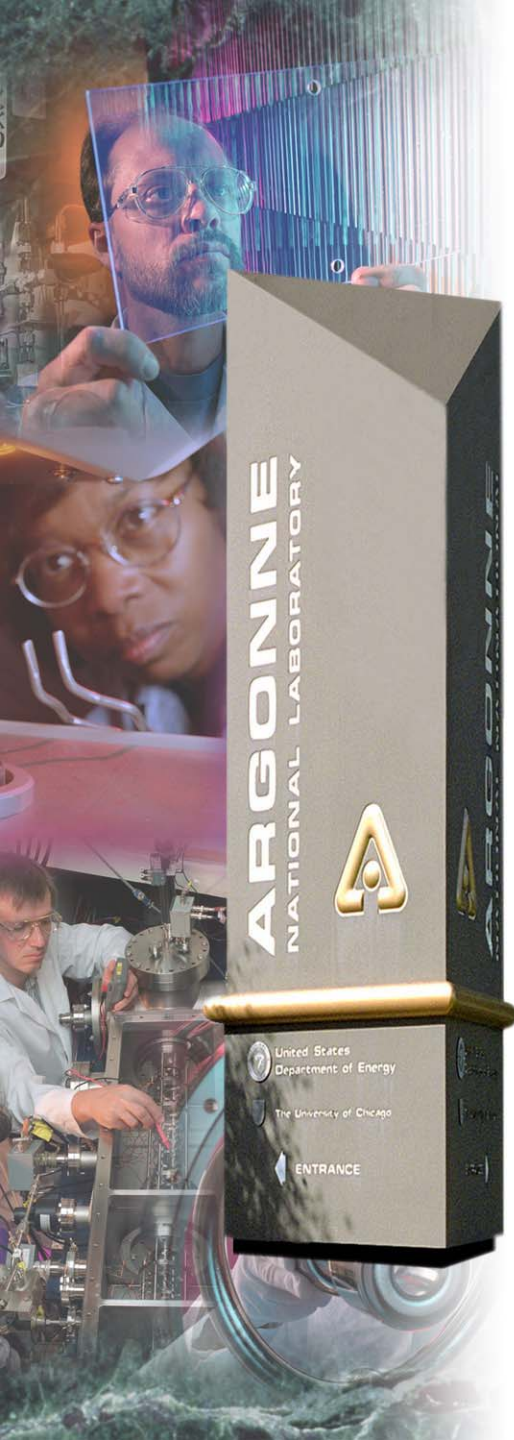


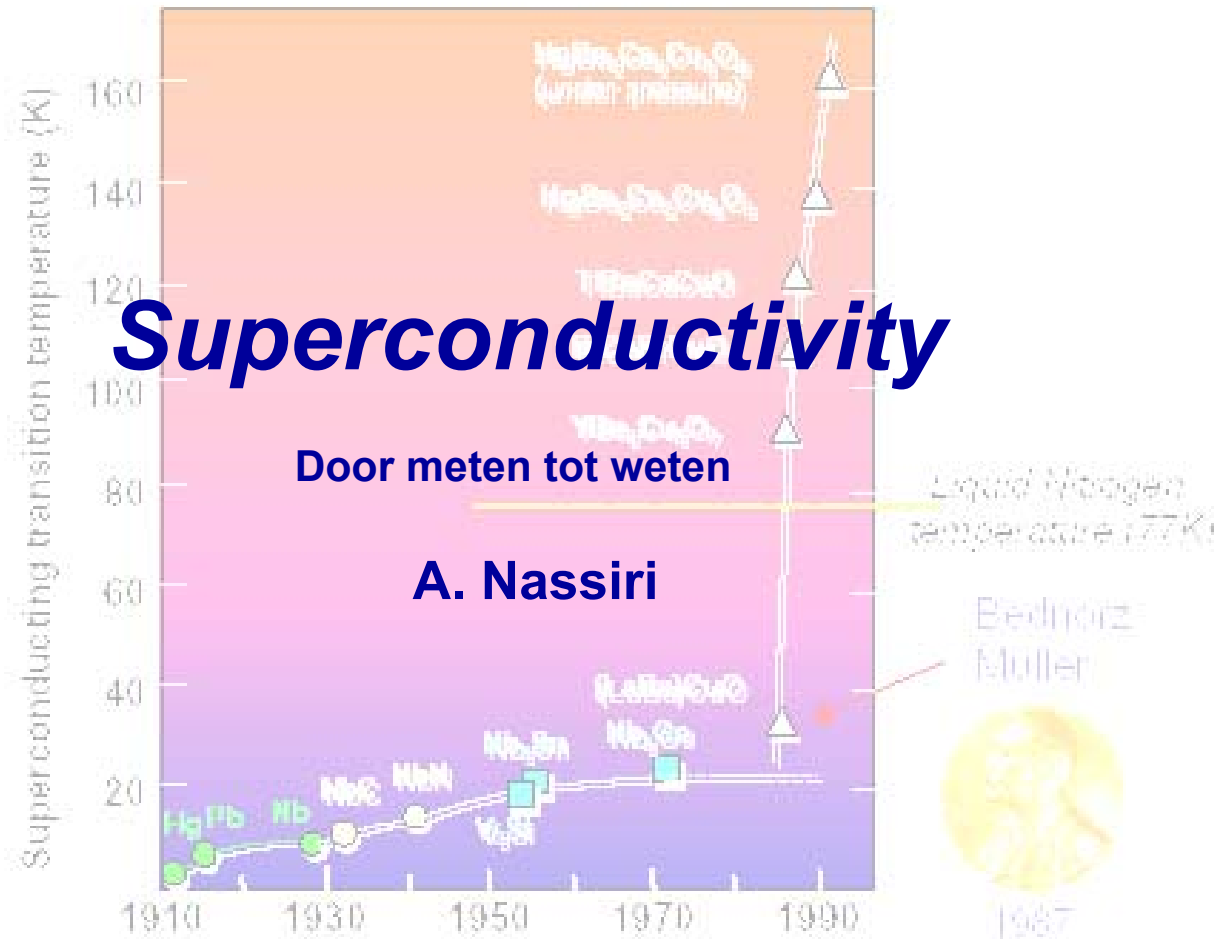
"Hey, no problem!"



Superconductivity

Door meten tot weten

A. Nassiri



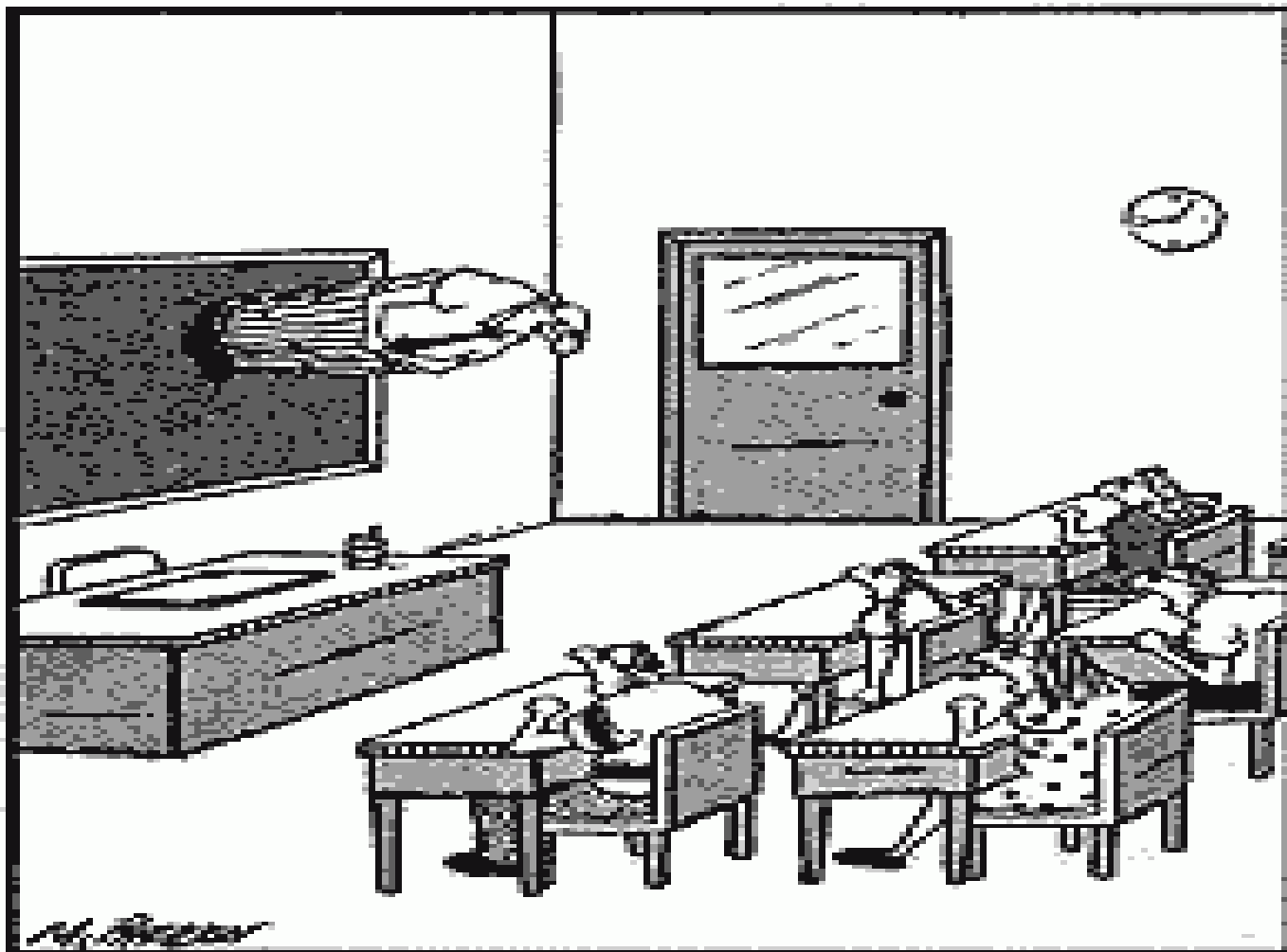
Argonne National Laboratory

Thursday, February 17, 2005



A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago





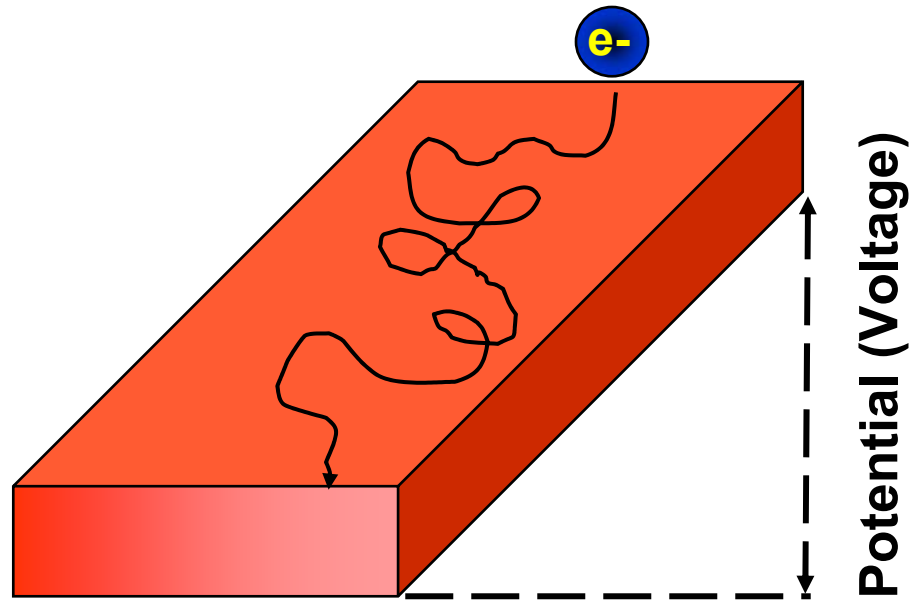
**"Good morning, and welcome to
The Wonders of Physics."**

Metals and Current



- $V = IR$
- Resistance
- Wires radiate power away as heat
- You pay for more electricity than you receive!
- Electrons “scatter” off lattice, and lose energy

Normal Conductors



Average time for the electrons to reach the bottom of the hill



Resistance

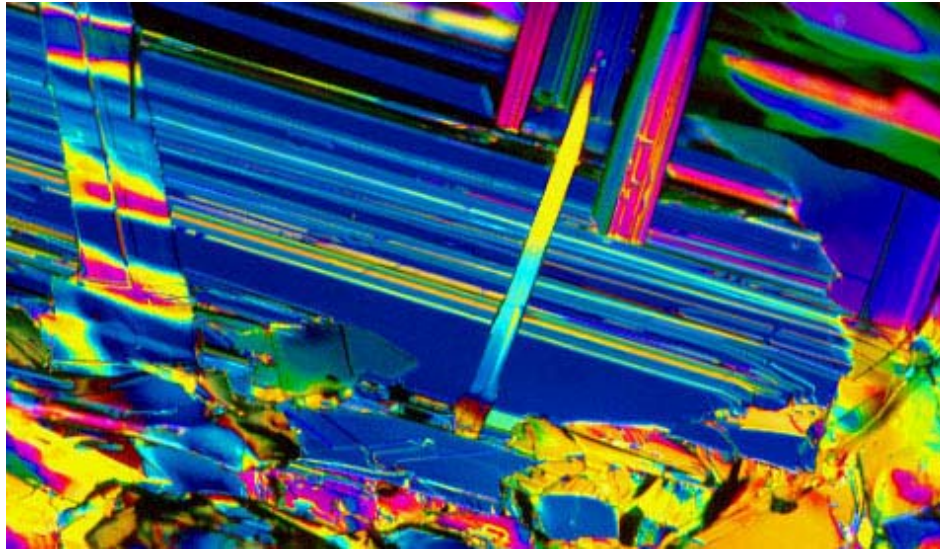
What is zero resistance



Some mornings, Floyd was sorry he ever bought a talking toaster.

		<i>Copper Wire</i>	<i>Heater Wire</i>	<i>Superconductor</i>
<i>Resistance: R</i>		<i>low</i>	<i>high</i>	<i>Zero!</i>
<i>Voltage: V=I x R</i>		<i>low</i>	<i>high</i>	<i>Zero!</i>
<i>Heater: power P=I x V</i>		<i>low (cool)</i>	<i>high (hot)</i>	<i>Zero! (cold)</i>

Superconductors



- Carry current perfectly
- Do not lose energy
- Current in a loop will run *forever*
- Expel magnetic fields (Meissner effect)



An example

1 tesla whole-body MRI

RT copper vs. superconducting

Unit	Power [kW]	Operation	Cost [\$ /year]
RT Copper	2,000	2,500 hrs+	~500k
Superconducting	20*	Continuous	~20k

* Refrigeration.

+ 10 hrs/day; 250 days/year.



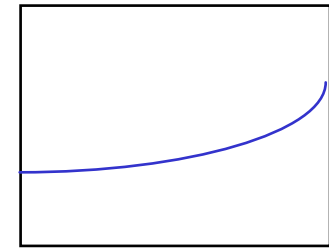
What is a superconductor?

Superconductors are materials which below a critical temperature have a resistance of zero.

- Superconductivity is a low-temperature phenomenon.



ρ



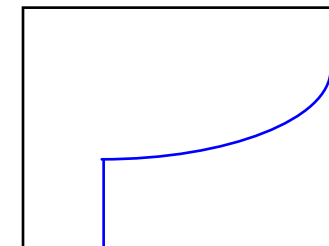
T

Metallic Conductor

$$\rho = \rho_o [1 + \alpha(T - T_o)]$$

- For superconductors, resistivity drops (almost) to zero below a critical temperature.

ρ



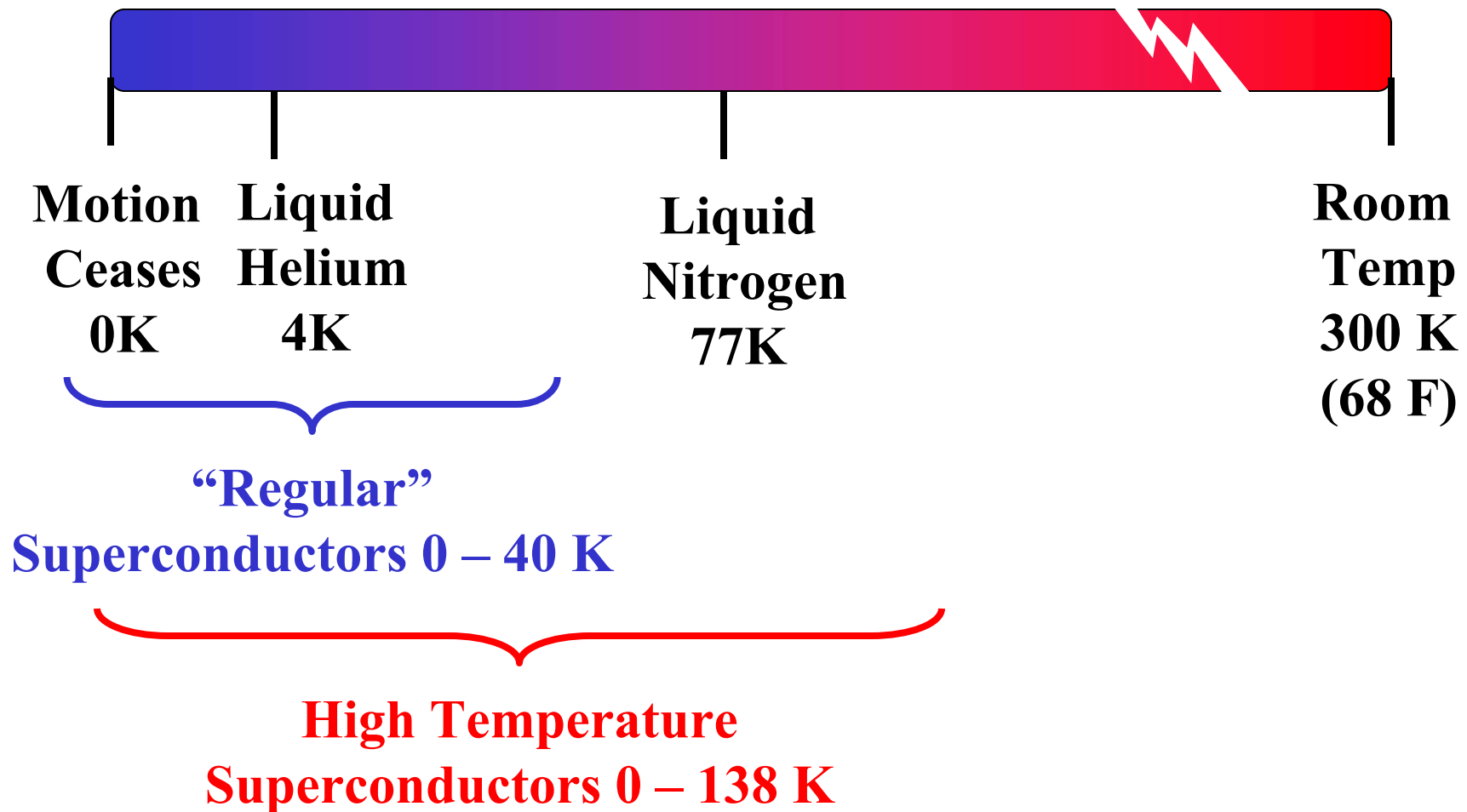
T

Superconductor

$$\rho \rightarrow 0 \quad \text{for} \quad T \leq T_c$$

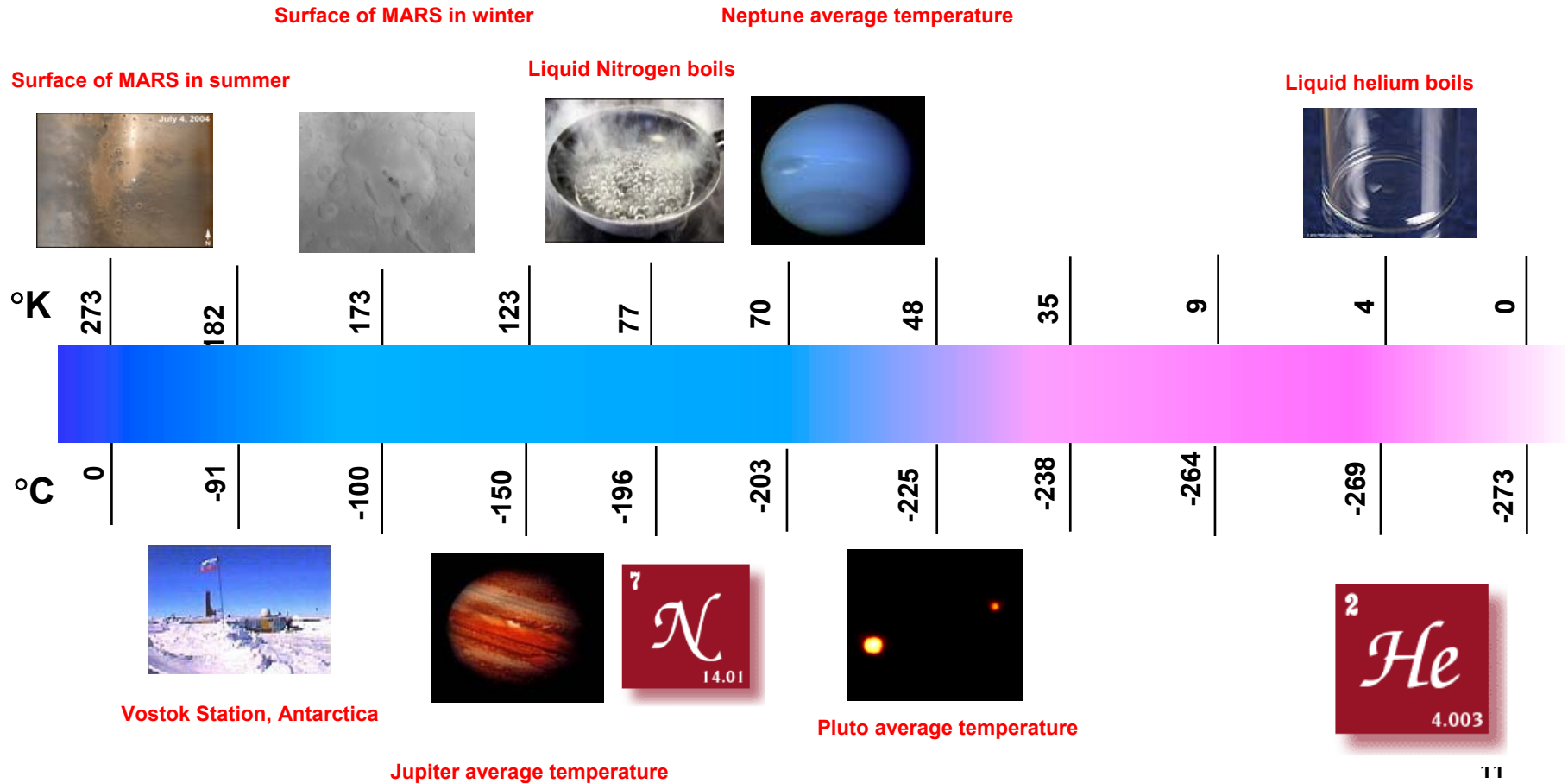


Low Temperature

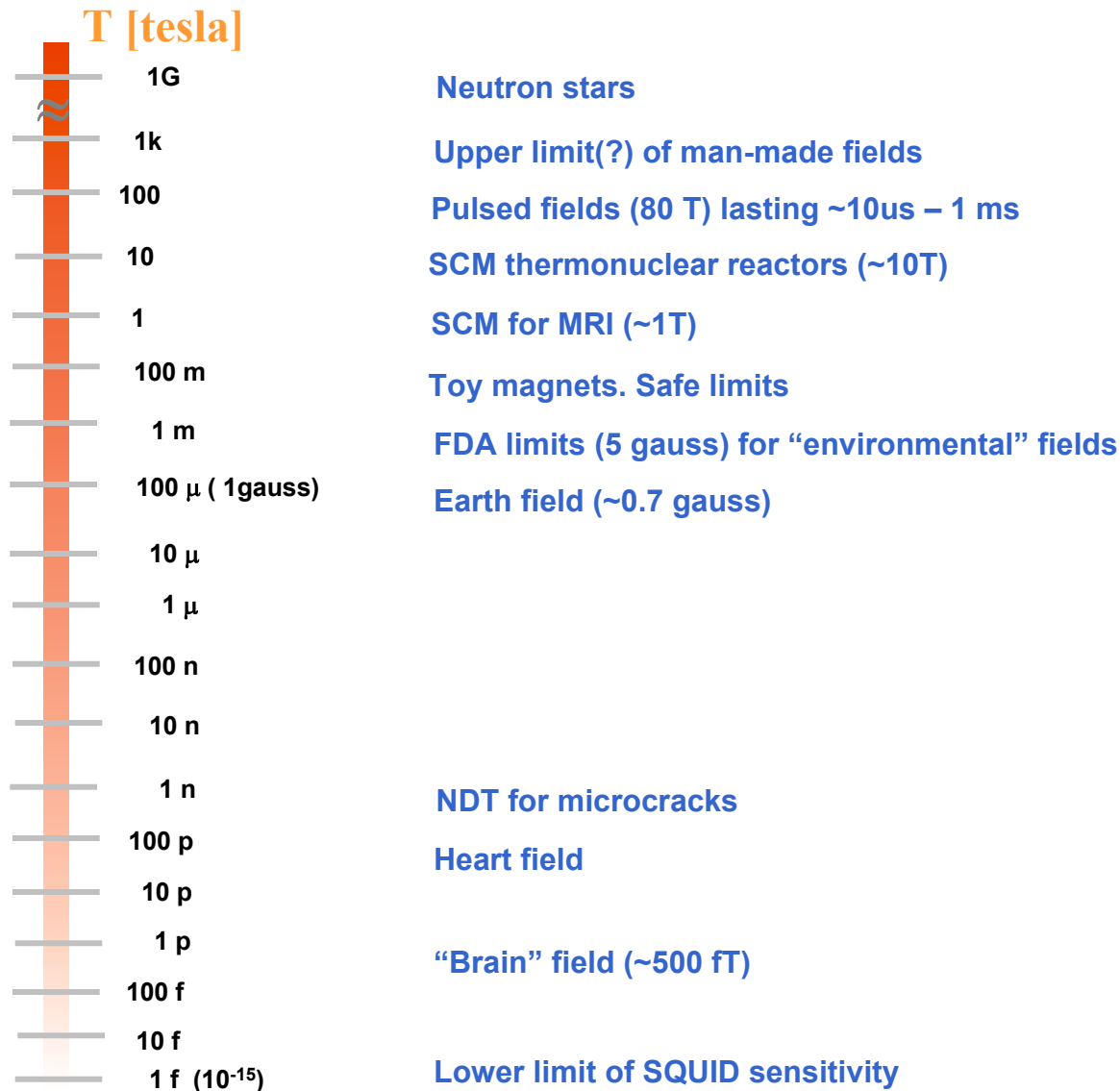


Low Temperature

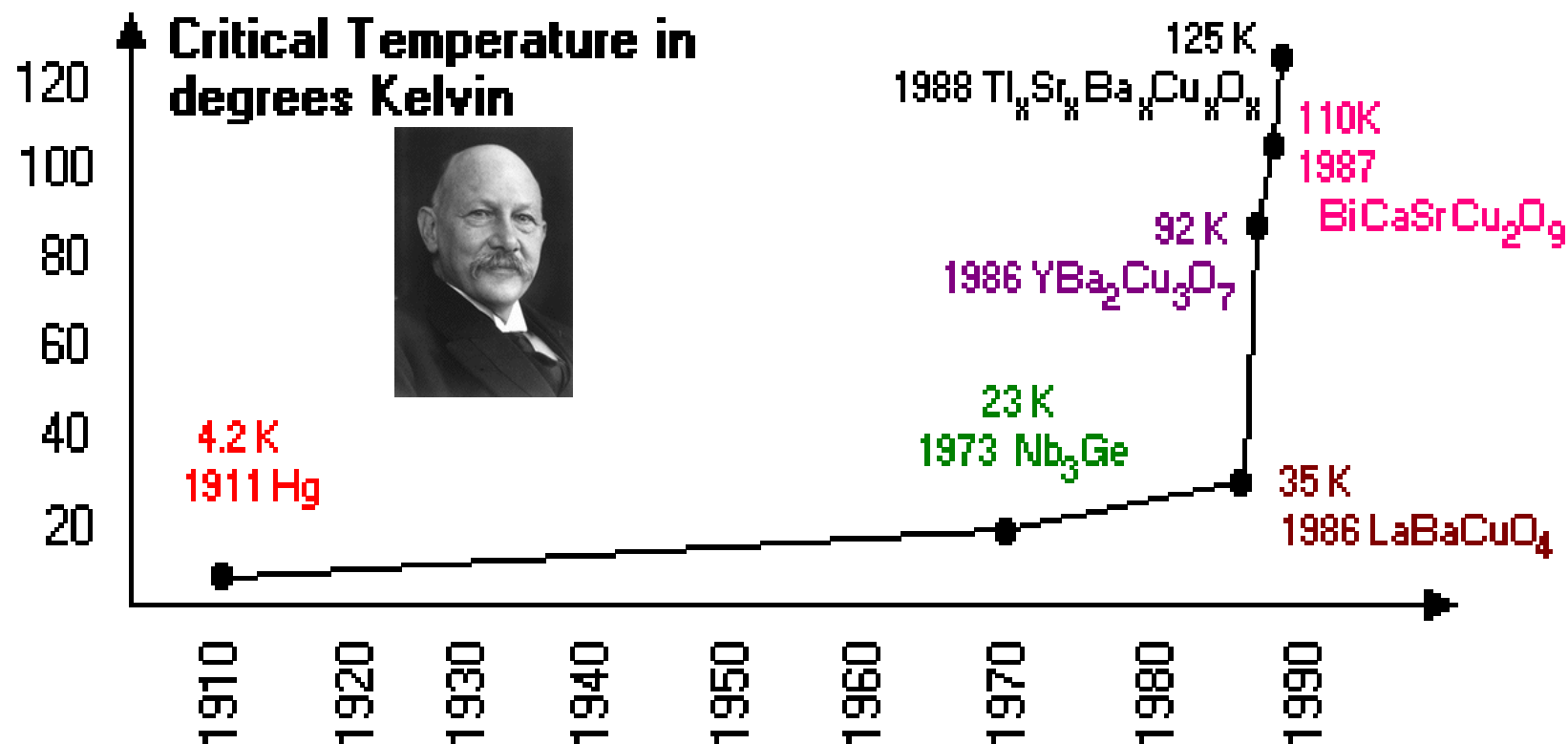
$$^{\circ}\text{K} = ^{\circ}\text{C} + 273 \quad ^{\circ}\text{C} = 5/9(^{\circ}\text{F} - 32)$$



Magnetic field spectrum



Superconducting Race



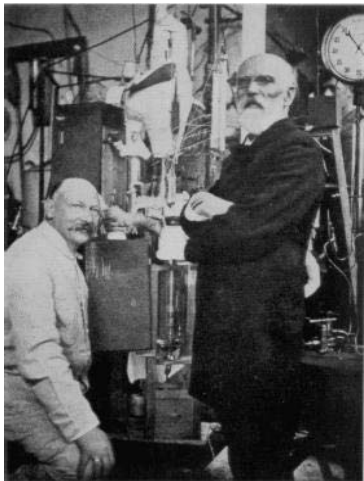
It all started.....

1911: H. K. Onnes, who had figured out how to make liquid helium, used it to cool mercury to 4.2 K and looked at its resistance:

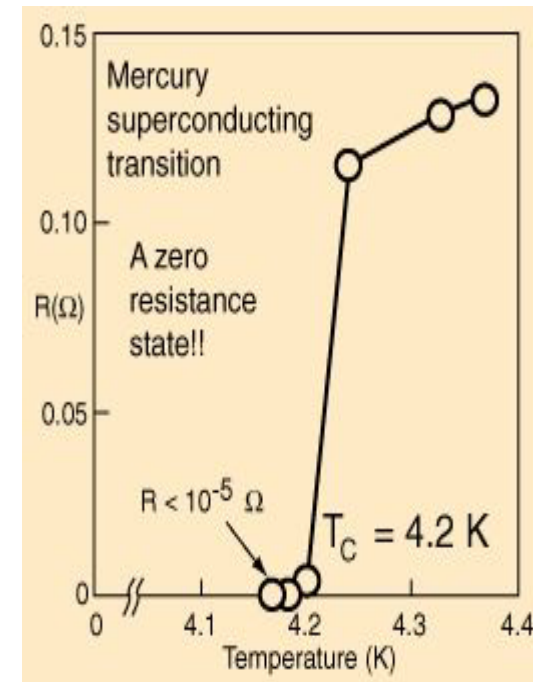
At low temperatures the resistance of some metals $\rightarrow 0$, measured to be less than $10^{-16} \Omega$

Heike Kamerlingh Onnes received The Nobel Prize in Physics 1913

"for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium"



Leiden University 1911



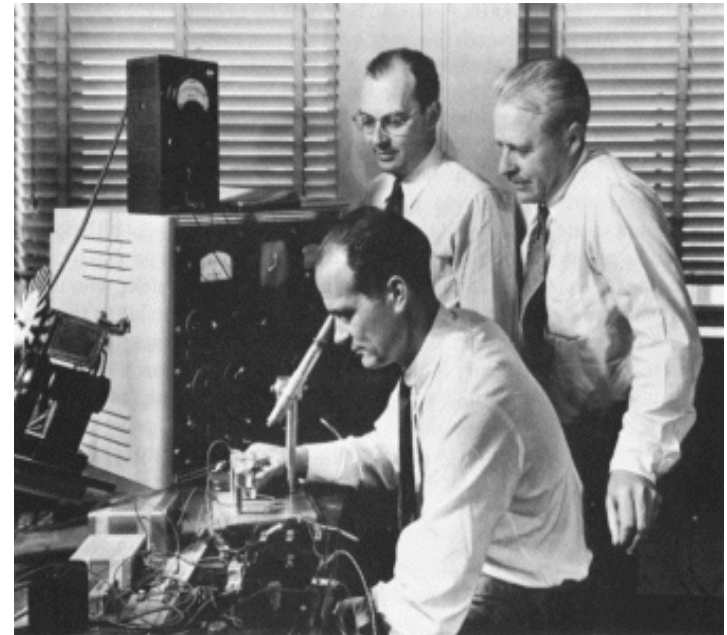
It all started.....

- ❖ 1957: Bardeen (UIUC!), Cooper, and Schrieffer (“BCS”) publish theoretical explanation, for which they get the Nobel prize in 1972.)

● **It was Bardeen's *second* Nobel prize (1956 – transistor)**



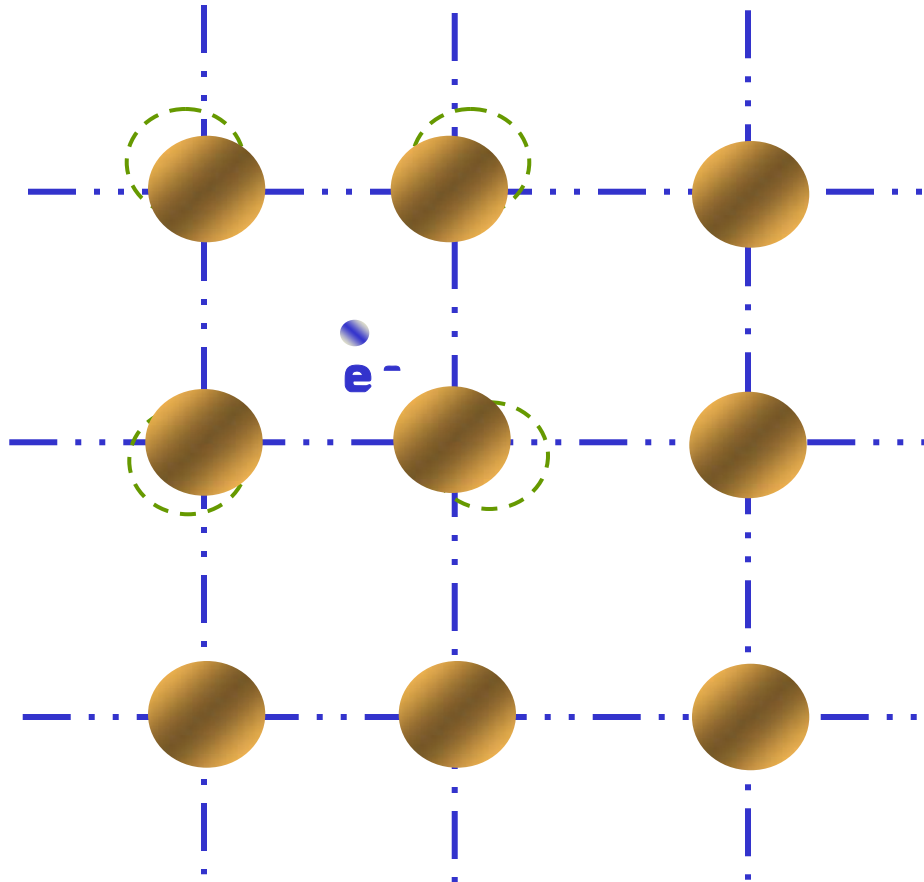
John Bardeen, Leon Cooper, and John Schrieffer – Nobel Prize 1992 (BCS Theory of Superconductivity)



John Bardeen , Walter Brattain, and William Shockley



How does it work?



- An electron polarizing positive ions in its vicinity

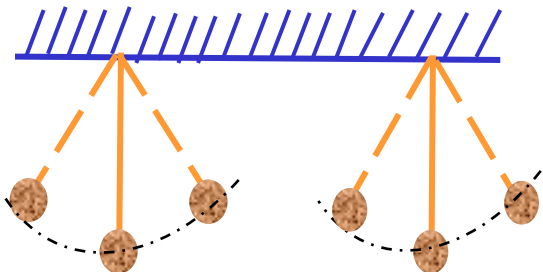
- It creates an attractive potential

- A second electron follows in the wake of the 1st electron

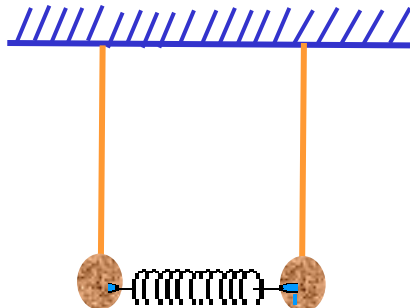
- This pairing is mediated by the exchange of energy with the lattice (Phonon)

How does it work?

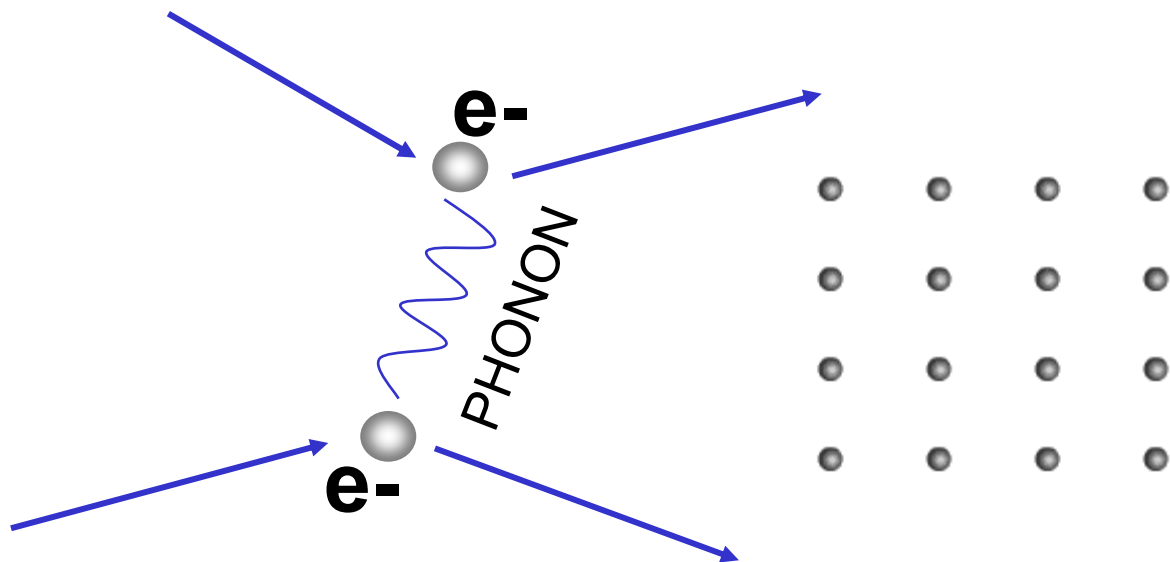
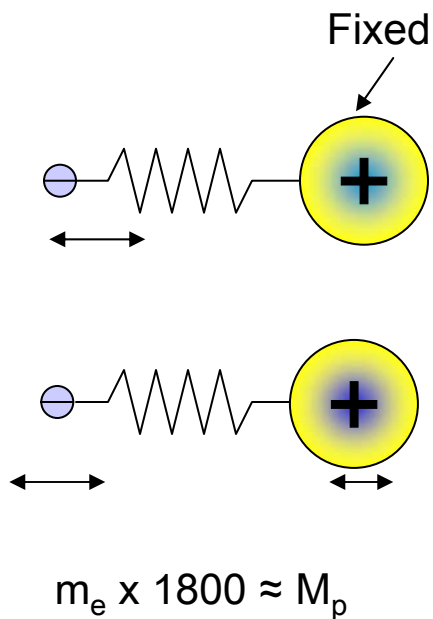
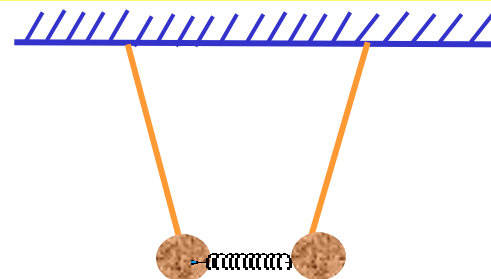
Two independent pendulums
Oscillating independently



Two coupled pendulums via spring
with a given stiffness



Oscillation mode that two
masses are attracted via spring
action



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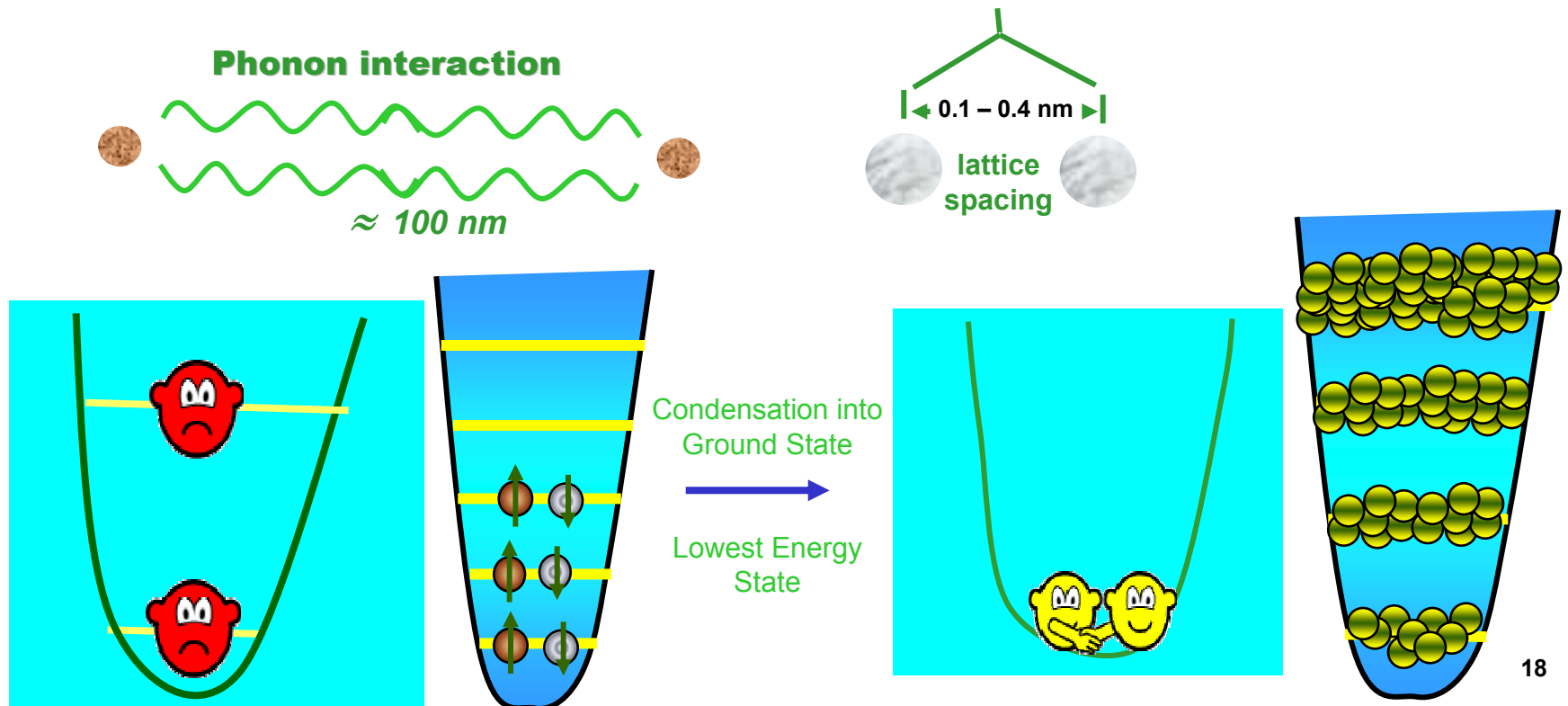


Cooper Pairs

In superconductive state, electron pairs are coupled (via phonon) over a range of hundreds of nanometers.

BCS Theory - UIUC

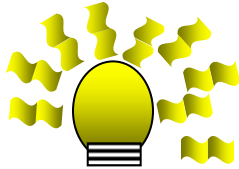
These coupled electrons (called **Cooper Pairs**) assume a new character and occupy (**condense**) into the lowest energy state (**ground state**).



What is Phase Coherence?

Incoherent

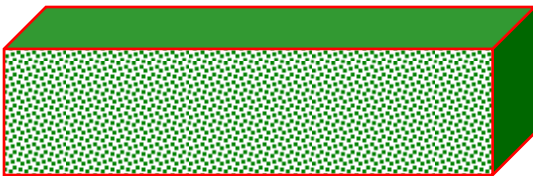
Light bulb:



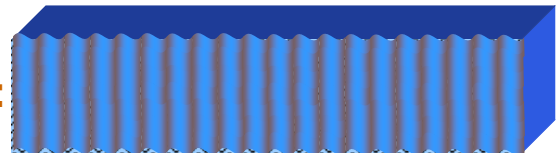
Fans at a soccer game:



Normal metal (electrons):



Superconductors (Cooper Pairs):



Coherent

LASER :



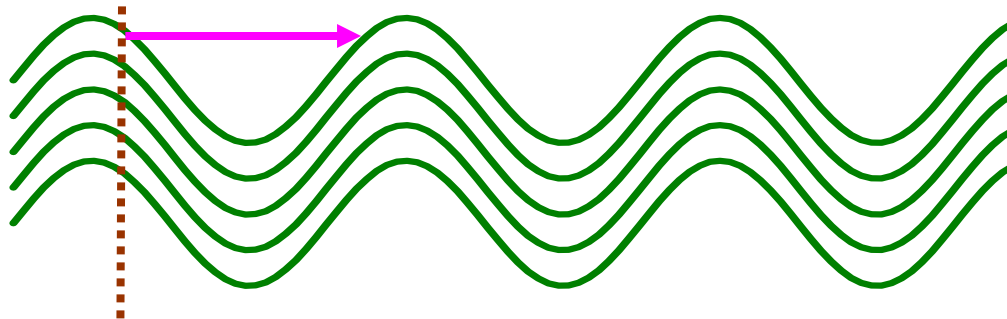
Vee formation:



Phase Coherence

Like LASER, Cooper Pairs have phase coherence

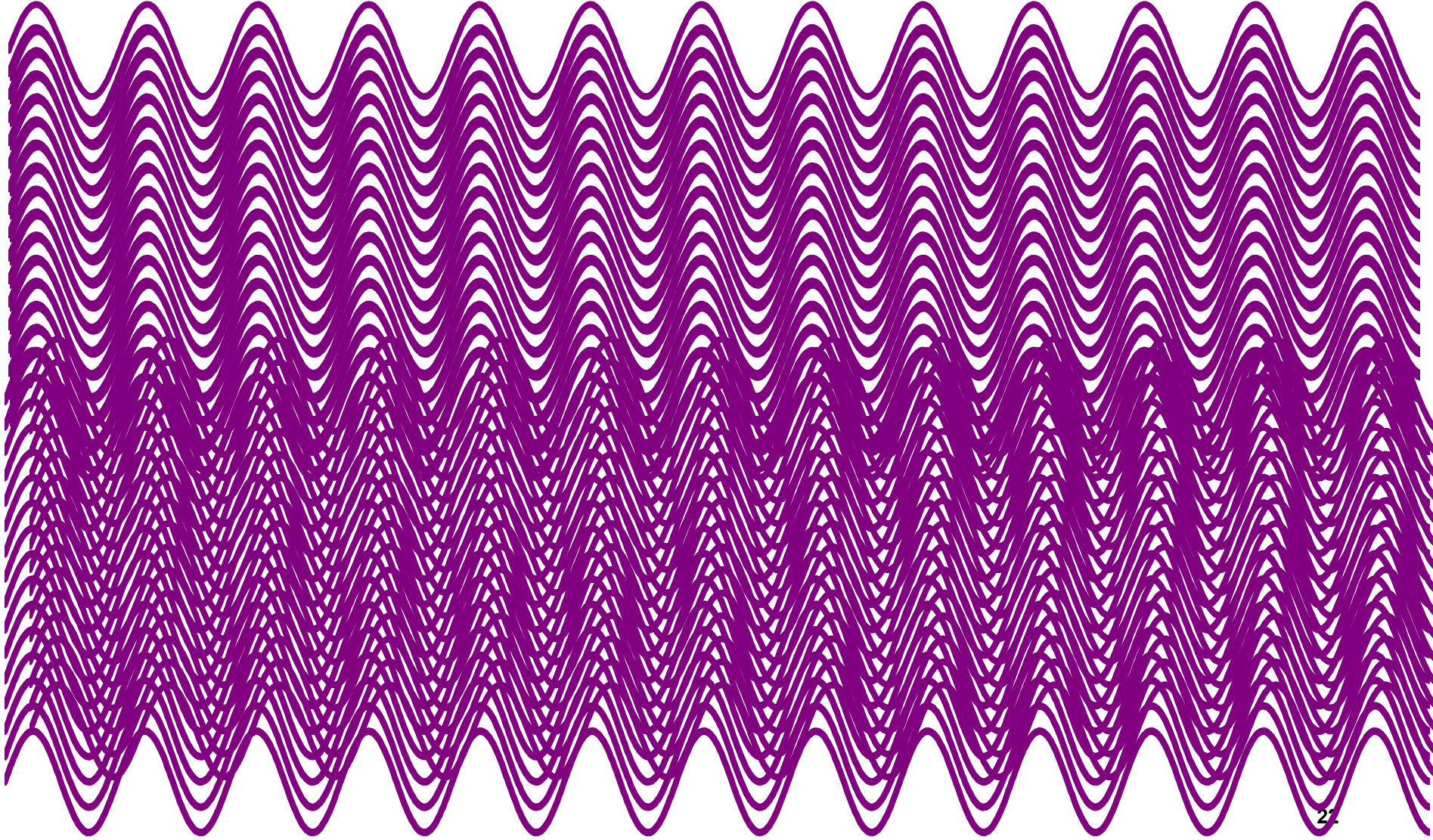
Phase Coherence means that the waves are “in-step” or “in phase”.



Phase Incoherence



Phase Coherence



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